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# BUILDING MATERIALS AND INDOOR AIR QUALITY

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New building materials, products, and furnishings are known to emit a large number of organic chemicals into indoor air.[3,5,6,13,14,17,19,21,33,34,36] Building occupants' sickness, irritation, and discomforts are often blamed on the presence of such chemicals in indoor air.[21,31] Most of the chemicals of concern are either volatile organic compounds (VOCs) or semi-volatile organic compounds (SVOCs). VOCs have vapor pressures down to $10^{5}$ or $10^{6}$ millimeters of mercury (mm Hg); SVOCs have lower vapor pressures. Building designers, owners, operators, occupants, and product manufacturers are increasingly concerned about problems related to indoor air contaminants emitted from building products and furnishings.[14,34]

## EFFECTS OF VOLATILE BUILDING COMPOUNDS ON BUILDING OCCUPANTS

The health effects of most VOCs emitted from building materials are not well understood, but many are known or suspected human irritants and carcinogens. In one study, Lars Molhave of Denmark found that 82% of commonly emitted VOCs are known or suspected mucous membrane or eye irritants, and 25% are known or suspected human carcinogens[18] (Table 1). Thus, exposure to these VOCs is implicated in many problem buildings involving indoor air quality complaints. There is also reason for concern about long-term exposure to low levels of many of these compounds.

OCCUPATIONAL MEDICINE: State of the Art Reviews—
Vol. 4, No. 4, October–December 1989. Philadelphia, Hanley & Belfus, Inc. 

*TABLE 1.* Health Effects of 52 Organic Compounds Emitted from 42 Building Materials*

| | Mucous Membrane Irritants (%) | Carcinogens (%) | Odorous Compounds[b] (%) |
|---|---|---|---|
| Unknown | 2 | 75 | 60 |
| None | 17 | | |
| Known | 42 | 25[a] | 30 |
| Suspected | 40 | | |

* From Molhave L: Indoor air pollution due to organic gases and vapours of solvents in building materials. Environ Int 8:117 127, 1982, with permission.
[a] Two compounds are suspected human carcinogens.
[b] Average concentration exceeds estimated or known odor threshold.

## Control Measures

Much can be done to reduce building occupants' exposures to emissions from building materials and products. Control measures include careful planning, specifications, and selection, modification, and treatment of products, as well as special installation procedures and proper ventilation system operation.

There have been various efforts to characterize (identify and quantify) emissions from building products. Emission rates or source strengths characterized by the testing of building products and materials can be useful when making decisions regarding product selection and use. The information is also useful when prescribing ventilation system operational protocols to maintain acceptable indoor air quality and when assessing complaints associated with indoor air quality problems.

*Solutions.* Special procedures can prevent or remedy indoor air quality problems that result from material emissions. Many office buildings now operate under special ventilation protocols prior to or shortly after initial occupancy. These include increased ventilation during material installation and initial building occupancy in order to reduce residual airborne VOC concentrations during the early occupancy period.

A procedure known as a "bake-out" has been used to accelerate the emissions of chemicals from newly installed materials, products, and furnishings.[5,6,14,16] In this procedure (described in more detail in the article by Girman in this issue), the building is heated to temperatures above 90° with very low outside air ventilation for more than 24 hours. The larger the period of elevated-temperature and the higher the temperature achieved, the more effective the bake-out. The effect is achieved by the increase in vapor pressure of the chemicals of concern. They are driven out of building materials and into building air. Then, the building is ventilated with 100% outside air for more than 24 hours before normal occupancy.

The bake-out procedure is most effective in reducing emissions from newer materials. However, it has been applied as a remedy in some indoor air quality problem buildings. Caution should be exercised to avoid damage to the building structure or contents during the bake-out as a result of excessive temperature or humidity changes.[5,6]

*Limitations.* There are several factors that severely limit the use of product selection to protect occupants from toxic or irritating effects of indoor air contaminants. There is not sufficient knowledge regarding the health and irritation





effects of exposure to very low concentrations of most indoor air contaminants. It is hard to interpret the effects of exposure to low levels of a large number of different organic chemical compounds.[20] Contaminants from other sources, especially occupant activities, can be much greater contributors of VOCs in indoor air than product emissions.[9,28]

Products change over time as a result of manufacturing variations, and products change significantly as a result of their normal aging process when in use. Ventilation system operation variables can significantly affect airborne concentrations of and occupant exposure to chemicals emitted from building products.

In spite of these limitations, a careful review of available data concerning emissions and health effects, as well as the judicious use of ventilation, can effectively reduce occupant exposure to toxins and irritants in building materials, products, and furnishings. The quantity and composition of emissions from substantially similar products can vary significantly. Therefore, building design or evaluation of problems in existing buildings should include careful consideration of material emissions as sources of indoor air contaminants.

## BUILDING MATERIALS EVALUATION

Evaluating building materials and furnishings will assist in selecting products for new construction, remodelling, renovation, or refurnishing. The process described below has been used effectively in conjunction with the design of several new buildings, ranging from individual residences to extremely large office buildings. The same process and its criteria can be used to assist in the evaluation of sources considered significant in the etiology of health problems associated with occupancy of particular buildings or building types. When particular chemical compounds are identified in indoor air, possible sources may be identified using published information.[10,12,23,25,27,28,37] Appendix A contains a listing of compounds found in indoor air or in emissions tests of building materials.[34]

### Elements of the Materials Evaluation Process

The materials evaluation process may be used as a design tool or after the fact to identify likely sources of contaminants when attempting to explain problems in buildings. The process is divided into four major phases as follows:

1. **Identifying Target Products:** Familiarization with the overall building design and general review of products and materials to identify those considered likely to emit toxic or irritating chemicals in the completed building.
2. **Screening Target Products:** Review of suspect products and materials based on printed information from manufacturers and information in the open literature.
3. **Emissions Testing:** Testing of selected materials to determine chemical content, emissions rate, or change in composition due to environmental exposure.
4. **Evaluation and Recommendations:** Review and analysis of results and recommendations for materials selections, modifications, or handling to control indoor air contamination. Negotiation with product manufacturers, suppliers and installers to modify products or their installation and use.

## PHASE 1. IDENTIFYING TARGET PRODUCTS

Literally hundreds of separate products are used in most building projects, whether they be simple residences or complex skyscrapers. In order to make the

materials evaluation activity manageable, "target" products are identified based on the potential for occupant exposure to their emissions and the seriousness of such exposure.

Potential occupant exposure is a function of the emission (off-gassing) characteristics and the quantity and nature of the material used in the building. The seriousness of exposure is a function of the toxic or irritating effects of the emitted chemicals and the susceptibility of the exposed population.[20] A preliminary review of the building products and furnishings will result in a "short list" of target products for more detailed review.

To identify target products, it is important to consider the overall building design, the anticipated use of space, and the possible material and product selections. This is followed by a review of the intended use of major materials. In addition to indoor air quality considerations, the criteria for selection of products may include maintenance requirements, cost, expected useful life, acoustic performance, aesthetic effects, and functional performance. The quantities and applications contemplated for each major product are important considerations.

A material's surface characteristics will affect its emissions rates as well as its potential to act as an adsorbent and re-emitter for airborne VOCs. Textiles, fabrics, and insulation materials usually have very large surface areas. Their texture results in an effective surface area many times larger than their plane geometry surface area.

At this point, all questionable products and materials are considered for screening in Phase 2. In general, the list of target materials will include adhesives, paints, caulks, sealants, and insulations, as well as floor coverings, wall coverings, ceiling system, HVAC duct materials, and most furnishings. Table 2 lists many products of concern in offices.

## PHASE 2. SCREENING TARGET PRODUCTS

Screening of target products is done by determining (1) their quantity and distribution in the building, (2) their chemical composition, (3) the stability of chemical substances of concern, and (4) the toxic or irritation potential of their major chemical constituents. The result of this screening process is the identification of products and materials for testing or other evaluation.

*Quantitative Assessment.* Determine the extent of use and use per unit of floor area or building interior volume. On this basis, materials such as floor coverings and ceilings tiles are considered significant due to the large extent of their use—each has virtually 100% coverage (one square foot of material per square foot of floor area). If the ventilation system uses the concealed space above a suspended ceiling as a return air plenum, then both the upper and the lower surfaces of the ceiling tiles are exposed to the circulating indoor air. Thus, ceiling tiles approach 200% (of floor area) coverage.

Office work station "work surfaces" (desktops) usually have between 15 and 35% coverage, depending on occupant density and work station design. In modern work station component systems, this desktop material is often used for shelving in work station closets, which can add an additional 10 to 20% to the coverage ratio. This material is usually exposed on both upper and lower sides and is considered especially significant due to the normally large amount of contact or close proximity between the office workers and the product. The work surface is often a plastic laminate covering a wood and particleboard core. If the laminate does not completely seal the unit, the interior materials are exposed to





*TABLE 2.* Typical Materials of Concern in Office Buildings*

- **Site work and foundations:**
  - Insecticides and other soil treatments
  - Waterproofing, particularly petroleum derivatives
  - Fertilizers
- **Structure and envelope:**
  - Wood preservatives
  - Concrete sealers, curing agents
  - Caulking
  - Sealants
  - Joint fillers, gaskets
  - Glazing compounds or gaskets
- **Insulations:**
  - Thermal insulation
  - Fire proofing
  - Acoustic insulations
- **Interiors and finishes:**
  - Subfloor:
    - underlayment (particleboard, plywood, chipboard)
  - *Flooring systems:*
    - flooring or carpet adhesive
    - carpet backing or pad
    - carpet or resilient flooring
  - Partitions:
    - wall coverings
    - adhesives
    - paints, stains, wood preservatives
    - paneling
  - Furnishings:
    - textiles
    - composite wood products (particleboard, plywood, hardboard, chipboard)
  - Ceiling systems:
    - ceiling tiles
    - panels
- **HVAC systems:**
  - Duct insulations:
    - condensate pan insulation
  - Duct sealants
  - Chemicals:
    - cooling tower water treatment
    - boiler water treatment
    - humidifier water treatment

* From Levin H: Indoor Air Quality Update, March 1989. Arlington, MA, Cutter Information Corp, 1989, with permission.

the air stream and emissions are larger. Completely sealed units will have much lower emissions from the materials inside the core.

The coverage of work station interior partitions (normally about half-height on three and one-half sides of each work station) varies with occupant or work station density. It generally approaches or exceeds 200% of the floor area in open office areas where the work stations are used. In denser installations it can exceed 300%. Again, two sides of the product are exposed to the indoor air, and the product is also in close proximity to the office workers. Furthermore, fabric-covered partitions have very high surface area due to the texture. This creates increased surface area for emissions and for adsorption and re-emission.

*Chemical Content.* During the screening phase, chemical content is assessed from published general information on building products and materials, information obtained from the building's interior designers, or from manufacturers' and suppliers' product literature and data sheets.[12,25,36] These are obtained by requiring all potential vendors to provide Manufacturer's Safety Data Sheets (MSDSs) for all products assembled by them and the names of suppliers of each product not assembled by them. Additionally, they should be required to provide contact information for each of their suppliers and to request the contact individual to cooperate with the design team. These secondary suppliers and manufacturers are then contacted, and additional MSDSs and other information are obtained.

MSDSs are United States Occupational Safety and Health Administration (OSHA) mandated documents listing all hazardous substances contained in the product they cover. MSDSs are generally available for most products of interest, although they vary in quality, and they may lack actual content information due to "trade secrets" exemptions in the reporting requirements. OSHA requires that MSDSs be available to workers for all hazardous substances to which the worker will be exposed. Thus, whether in a factory or at the construction site, each substance used in building materials, products, and furnishings is theoretically covered by an MSDS.

To illustrate, of the large number of chemicals involved in furnishings, approximately 30 chemicals are used to produce the fabric covering interior partitions. The name of the chemical and its function in the manufacturing process or the finished product should be listed by the manufacturer to provide a more complete understanding of the finished product. The fabric is attached to a metal, lumber, or tempered hardboard frame, usually by an adhesive. The panel contains acoustic material, often fibrous glass batting adhered to a hardboard sheet. There are also metallic components used for the exposed frame of the panel and for the adjustable legs that support the panel above the floor.

In general, aspiring vendors are very cooperative in providing the required information. It should be pointed out that the larger the scale of the project, the more likely vendors will be willing to cooperate. Designers working on smaller projects might aggregate the information collection process for several projects or collect the information over a 1-year or 2-year period to develop an attractive market potential that will induce manufacturer cooperation.

*Chemical Stability.* Stability (chemical emissions) assessments are done by reviewing the vapor pressure and molecular weight data for chemicals of concern, as identified on the MSDSs. Many sources can be used to obtain the data.[23,27,35] A particularly useful source is the Table of Solvent Drying Time in *Industrial Ventilation.*[2]

Additional information on potential emissions into building air is obtained by reviewing emissions test reports and articles in the published literature.[9,11,14-17,28,32-34,36]

Emission factors can vary significantly—up to a factor of 1000—for different brands of similar products.[11,28,33] Therefore, it is important to obtain as much information as possible about the types and quantities of constituents in a given product. Although such a paper evaluation cannot be definitive, it can be useful in selecting potentially acceptable products. It also can be useful in identifying specific compounds to be measured if laboratory testing is performed.

*Toxicity Evaluation.* Toxicity or irritation potential of constituent compounds is evaluated using standard reference sources.[1,4,7,22,23,27,29,35] For example, Sax lists a "summary of toxicity statement" or rating (THR) for each substance covered.[27] Ratings of "none," "low," "moderate," "high," or "unknown" are given. Routes of entry are given for specified toxic effects. $LD_{50}$ (lethal dose for 50% of experimental animals) values are given for various exposure routes and experimental species. Human irritation potential and target organs or sites are also listed and carcinogenic and mutagenic assessment is reported.





NIOSH's *Registry of Toxic Effects of Chemical Substances, (RTECS)* 1985–1986, Volumes 1–5 plus a Volume 3a and a User's Guide, provide an annotated listing of toxicity and irritation research for tens of thousands of chemical substances.[23] *RTECS* is available in hard copy or on-line through Toxnet (National Library of Medicine), and on CD-ROM from CCInfo Disc. *RTECS* contains a comprehensive list of alternative trade and generic names by which products may be known or marketed, chemical formulas, and cross-references to the Chemical Abstracts Service (CAS) number for each chemical.

EPA is now developing a data base on building materials emission rates. There also exists a large data base developed by NASA for materials used in spacecraft design and operation. Work currently in progress will make both of these data bases more accessible and useful to the interested professional.

From the screening process, determinations are made regarding materials that will require laboratory testing. A combination of high volatility and moderate toxicity would result in further consideration of the substance and the product. A substance of very low volatility and moderate toxicity would be examined in terms of the quantity of the product and the quantity of the substance in that product. No algorithm has been established for this evaluation; a qualitative assessment is the most reasonable approach, given the limited amount of data currently available.

*Results.* The results of this screening process allow identification of the products most likely to emit significant quantities of irritating or toxic substances. These usually include the carpet system (carpet, pad or backing, and adhesive), office furnishings (work surfaces, shelving, and interior partitions), and the ceiling tiles. Storage systems, adhesives, caulking compounds, paints, sealants, and wood finishes are also materials of concern. Specific products considered or used for these applications may be evaluated by emissions testing:

## PHASE 3. EMISSIONS TESTING

*Test Methods.* Test methods include bulk testing and air sampling in an environmental chamber or from headspace. Headspace testing involves placing the sample in a closed container for a specified period of time, then sampling the air in the "head space" above the sample in the container. Air sampling can also be done in the completed building prior to, during, and after materials installation to develop air quality profiles of the installation.

Chamber tests can be conducted in a very small chamber (usually less than 0.1 $m^3$) or in a medium-size chamber capable of accommodating full-size samples. Cut samples create problems of distorted ratios between surface area and edges, and cuts through materials can expose materials not normally exposed in the assembled product. Sealing the edges reduces some of these effects. Room-size chambers can also be used, but they are expensive and require larger quantities of materials.

Ratios of materials surface area and weight to chamber volume and wall area should be kept reasonably similar to the ratios found in actual building

situations. Multiple materials tests may also be run to determine "sink" effects, which are the tendency of materials to adsorb airborne substances on their surfaces and re-release them to the air.

Air movement in the chamber should be at air change rates that approximate those found in buildings—between 0.5 and 5 air changes per hour. Humidity should be controlled during the chamber tests. Relative humidity is generally held close to 50% in most chamber tests. Airflow should be controlled within the chamber to assure good mixing and to minimize unusually high velocities at material surfaces. Introduction and removal of air from the chamber is through perforated headers placed diagonally from each other at the bottom and top of opposite chamber side walls.

Material samples are conditioned by placing them in the chamber at a controlled temperature and under forced air circulation for several hours or even days prior to testing. In order to best meet the purpose of the testing, handling of the material should resemble that employed in actual installation of the material in buildings. Products are stored in factory containers until tested. Once opened, they are kept in a normally ventilated room containing typical, new office furnishings until additional testing is conducted. Complete and careful record keeping is essential to accurate interpretation of testing results.

## Emissions Test Data

Several groups have performed emissions testing. Emissions tests have been done by researchers at EPA in Research Triangle Park, Saskatchewan Research Council, Lawrence Berkeley Laboratory, Oak Ridge National Laboratory, Georgia Tech, NASA, and a variety of private organizations.[11,17,19,28,33,34,36] EPA has begun development of a materials emissions data base.[38] Thus far, there is no comprehensive emissions data base, and it is not likely that such a data base will be produced soon. Any data base that is created will necessarily be of limited usefulness. The number of different types and brands of products used indoors is immense, and variations in each product can occur from one manufacturing run to another. Products are modified or replaced by manufacturers from time to time.[37]

The emissions testing that has been done is most useful in providing insights into the emissions process and in giving a general understanding of the wide range of emissions that might occur among products of similar use. It also allows us to better understand how to test products when such testing is performed. ASTM is currently developing a standard guide for the emissions testing in small chambers.[15] Specific test methods can be developed using this guide.

## Small Chamber Testing of VOC Emissions

Recently-reported small chamber tests of VOC emissions from various building materials, furnishings, and consumer products are producing important data for the control of VOCs in indoor air. Among such tests were those performed by Bruce Tichenor at EPA's Air and Engineering Research Laboratory, Research Triangle Park, North Carolina.[32,34] The purpose of the tests was to characterize emissions from a variety of sources of indoor air contaminants and to identify the effect of various factors on emission rates. These factors include temperature, relative humidity, air exchange rate, and chamber loading (material area compared to chamber volume).

Materials were screened using headspace testing and gas chromatography—mass spectrometry (GC/MS) analysis to identify the materials' emissions.





*TABLE 3.* Organic Compounds Identified Via Gas Chromatography/Mass Spectrometry*

| Material Product | Major Organic Compounds Identified |
|---|---|
| Latex caulk | Methyl ethyl ketone, butyl propionate, 2-butoxyethanol, butanol, benzene, toluene |
| Floor adhesive (water based) | Nonane, decane, undecane, dimethyloctane, 2-methylnonane, dimethylbenzene |
| Particleboard | Formaldehyde, acetone, hexanal, propanol, butanone, benzaledhyde, benzene |
| Moth crystals | Para-dichlorobenzene |
| Floor wax | Nonane, decane, undecane, dimethyloctane, trimethylcyclohexane, ethylmethylbenzene |
| Wood stain | Nonane, decane, undecane, methyloctane, dimethylnonane, trimethylbenzene |
| Latex paint | 2-Propanol, butanone, ethylbenzene, propylbenzene, 1,1'-oxybisbutane, butyl propionate, toluene |
| Furniture polish | Trimethylpentane, dimethylhexane, trimethylhexane, trimethylheptane, ethylbenzene, limonene |
| Polyurethane floor finish | nonane, decane, undecane, butanone, ethylbenzene, dimethylbenzene |
| Room freshener | Nonane, decane, undecane, ethylheptane, limonene, substituted aromatics (fragrances) |

* From Tichenor B: Organic emission measurements via small chamber testing. In Indoor Air '87: Proceedings of the International Conference on Indoor Air Quality and Climate, Vol. 1. Berlin, Institute for Water, Soil and Air Hygiene, 1987, pp 8-15.

Emissions tests were conducted using a small chamber (166-liter) with carefully controlled temperature, relative humidity, and airflow. The wet materials were placed in the chamber shortly after application to the test surface, and the first sample was collected 30 minutes after the chamber door was closed. Samples were collected on a tenax-charcoal combination and thermally desorbed. Approximately 10 compounds were analyzed by gas chromatography-flame ionization detection (GC/FID).[32]

Several types of materials were evaluated, including silicone caulk, floor adhesive, floor wax, wood stain, moth crystal cakes, and particleboard, among others. Organic compounds identified by the chamber tests are listed in Table 3. Note that several of the compounds on the list affect the central nervous system, some are known irritants, and several are known or suspected animal carcinogens or teratogens.

Table 4 shows the effect of air exchange rate and temperature on the emission rate of moth crystal cakes. As can be seen, the effect of temperature is

*TABLE 4.* Moth Crystal Emission Factors, Para-dichlorobenzene ($\mu g/cm^2$-hr)

| Air Exchange Rate (air changes per hour) | Temperature = 23°C | Temperature = 35°C |
|---|---|---|
| 0.25 | 1250 | 4600 |
| 0.5 | 1400 | 4850 |
| 1.0 | 1750 | 5700 |
| 2.0 | 2000 | 6700 |

quite large, and the effect of air exchange rate is significant also. The air exchange rates used are representative of the range of rates encountered in residences and public buildings such as offices or schools. The effect of temperature on emissions from moth crystals would be similar to that of other VOC sources.

The effect of time on the emission rates is shown in Figures 1-3.

*Implications.* Tichenor's work demonstrates that emission rates for "wet" materials can decrease rather sharply during the first few hours after application. However, a critical factor in the rate of decrease is the ventilation rate. For the caulking compound tested, emissions were close to zero after 6 hours at 1.84 ACH. However, at 0.36 ACH, significant emissions were still observed at 10 hours and the emission rate was declining very slowly (see Fig. 1). Emission rates were reasonably similar for three compounds, $C_4$ ketone, $C_8$ alcohol, and $C_7$ ester (see Fig. 2). This supports the notion that maximum available ventilation should be used during and immediately after the application of these materials.

It is noteworthy that concentrations of many of the compounds emitted from floor wax at 0.5 ACH decreased sharply during the first 12 hours from $10^3$–$10^4$ $\mu g/m^3$ to $10^2$ $\mu g/m^3$ The concentrations were still at $10^1$ $\mu g/m^3$ and decreasing at 48 hours when the experiment was stopped. This suggests that floors that are waxed on a Friday afternoon will still be emitting significant quantities of several compounds on Monday morning and beyond. This is true even with ventilation rates greater than normally encountered during weekends in unoccupied (no mechanical ventilation) schools and office buildings.

Based on the results of chamber, headspace, and test house environments, EPA researchers have constructed a model for predicting indoor air VOC

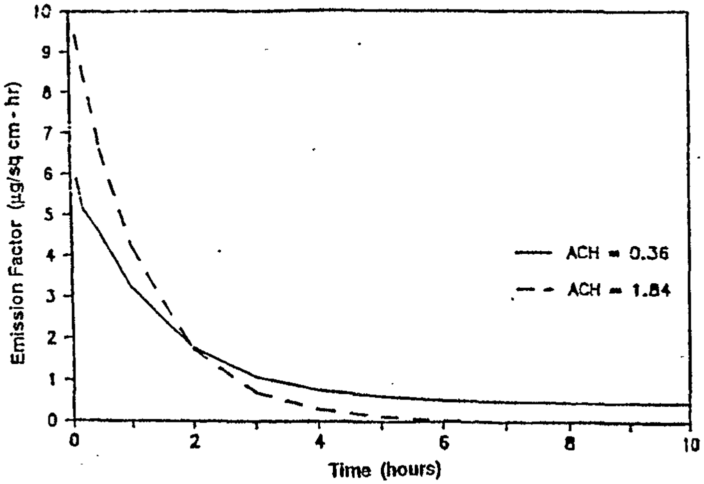


*FIGURE 1.* Emission factor vs. time—caulking compound. Total measured organics. From Tichenor B: Organic emission measurements via small chamber testing. In Indoor Air '87: Proceedings of the International Conference on Indoor Air Quality and Climate, Vol. 1. Berlin, Institute for Water, Soil and Air Hygiene, 1987, pp 8-15.



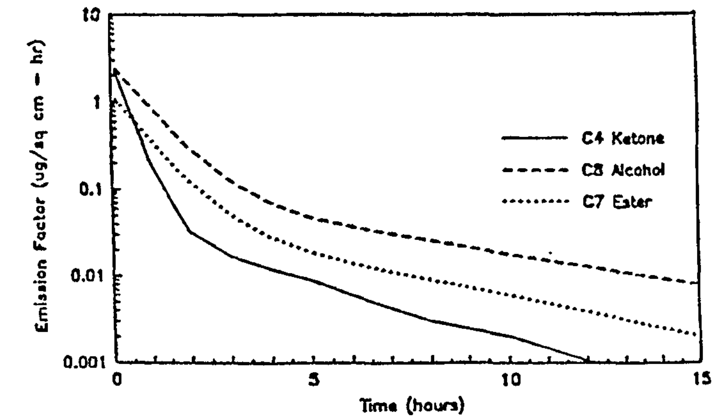


*FIGURE 2.* Caulk emissions vs. time—three compounds. T = 23°C; RH = 50%; ACH = 0.36. From Tichenor B: Organic emission measurements via small chamber testing. In Indoor Air '87: Proceedings of the International Conference on Indoor Air Quality and Climate, Vol. 1. Berlin, Institute for Water, Soil and Air Hygiene, 1987, pp 8-15.

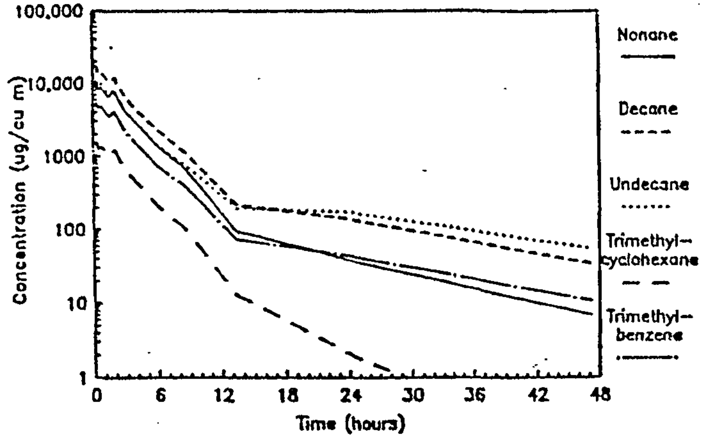


*FIGURE 3.* Concentration vs. time—floor wax. T = 22°C; RH = 50%; ACH = 0.5. From Tichenor B: Organic emission measurements via small chamber testing. In Indoor Air '87: Proceedings of the International Conference on Indoor Air Quality and Climate, Vol. 1. Berlin, Institute for Water, Soil and Air Hygiene, 1987, pp 8-15.

*TABLE 5.* Typical Emission Rates for Sources in a 400 $m^2$ Office Area* (Total Vapor-phase Organic Compounds, Except as Noted)

| Source† | Condition | Emission factor ($mg/m^2$-h)‡ | Assumed amount ($m^2$) | Emission rate (mg/h) |
|---|---|---|---|---|
| Silicone caulk | <10 hours | 13 | 1 | 13 |
| Silicone caulk | 10-100 hours | <2 | 1 | <2 |
| Floor adhesive | <10 hours | 220 | 30 | 6600 |
| Floor adhesive | 10-100 hours | <5 | 30 | <150 |
| Floor wax | <10 hours | 80 | 100 | 8000 |
| Floor wax | 10-100 hours | <5 | 100 | <500 |
| Wood stain | <10 hours | 10 | 100 | 1000 |
| Wood stain | 10-100 hours | <0.1 | 100 | <10 |
| Polyurethane wood finish | <10 hours | 9 | 100 | 900 |
| Polyurethane wood finish | 10-100 hours | <0.1 | 10 | <10 |
| Floor varnish or lacquer | NA | 1 | 100 | 100 |
| Particleboard | 2 years old | 0.2 | 300 | 60 |
| Particleboard (HCHO) | New | 2 | 300 | 600 |
| Plywood paneling (HCHO) | New | 1 | 1000 | 1000 |
| Chipboard | NA | 0.13 | 300 | 39 |
| Gypsum board | NA | 0.026 | 1000 | 26 |
| Wallpaper | NA | 0.1 | 1000 | 100 |
| Latex-backed carpet (4-PC) | 1 week old | 0.15 | 400 | 60 |
| Latex-backed carpet (4-PC) | 2 weeks old | 0.08 | 400 | 32 |
| Moth Cake (para) | 23C | 14,000 | 0.1 | 1400 |
| Dry-cleaned clothes (perc) | 0-1 day | 1 | 6 | 6 |
| Dry-cleaned clothes (perc) | 1-2 days | 0.5 | 6 | 3 |

Notes:
Para = paradichlorobenzene
HCHO = formaldehyde
Perc = perchloroethylene (tetrachloroethylene)
4-PC = 4-phenylcyclohexene, an odorous constitutent of some latex-backed carpets
NA = not available

* From Tucker WG: Emissions of air pollutants from indoor materials: An emerging design consideration. Presented at the 5th Canadian Building and Construction Congress, Montreal, Canada, November 27-29, 1988, with permission.

† Emissions data are typical only for the specified brands, models, or units that have been tested; the data do not represent all products of the source type listed. Product-to-product variability can be very high.

‡ Typical values selected by author based on data in "Database of Indoor Air Pollutants" (described in ref. 38).

concentrations.[30] Source strengths and ventilation rates were used in the model to compute some typical values which are shown in Table 5.

## Sealants and Caulks

Tests of a variety of sealant products performed by researchers at the Saskatchewan Research Council have found large variations in weight loss, rate of weight loss, and calculated complete drying times[11] (Table 6). A styrene ethylene butylene sealant lost 37% of its original weight during the first 48 hours and was projected to lose 61.7% upon complete drying at 79.3 hours. The emissions were petroleum hydrocarbons and xylene.



*TABLE 6.* Emissions Data from Various Sealant Products*

| Product description | Weight loss in % of original sample @ 48 hrs | @ fully dry | Calculated complete drying time (hrs) | VOC | THR* |
|---|---|---|---|---|---|
| Styrene butadiene rubber compound | 16.4 | 35.26 | 253.7 | Aliphatic hydrocarbons<br>Xylene | MOD<br>MOD |
| Oleoresinous | 0.68 | 4.42 | 1962.4 | Aliphatic hydrocarbons | NA |
| Polysulphide one-part | 0.56 | 6.2 | 4931.9 | Toluene | MOD |
| Butyl rubber | 5.26 | 17.69 | 434.3 | Aliphatic hydrocarbons | NA |
| Acrylic emulsion latex | 5.48 | 11.80 | | None detected | |
| Acrylic solvent-based | 3.26 | 13.51 | 1052.2 | Xylene | MOD |
| Polyvinyl acetate-based emulsion | 16.85 | 26.61 | | Negligible quantities | |
| Vinyl-acrylic emulsion latex | 12.70 | 30.05 | 317.3 | Petroleum hydrocarbons | NA |
| Asphaltic one-part | 1.37 | 8.09 | 4496.3 | Petroleum hydrocarbons | NA |
| Neoprene one-part | 18.00 | 32.75 | 214.0 | Xylene | MOD |
| One-part chlorosulfonated polyethylene | 4.4 | 14.38 | 446.7 | Xylene | MOD |
| Polyurethane one-part | 1.2 | 14.86 | 8269.4 | Xylene | MOD |
| Silicone | 2.06 | 4.49 | 487.2 | Xylene | MOD |
| Polybutene | 2.39 | 9.19 | 627.8 | Petroleum hydrocarbons | NA |
| Styrene butadiene rubber | 14.0 | 19.25 | 106.3 | Xylene | MOD |
| Neoprene blend | 17.4 | 23.21 | 101.4 | Methyl ethyl ketone<br>Xylene<br>Toluene | MOD<br>MOD<br>MOD |
| Styrene butadiene | 21.1 | 25.03 | 55.5 | Hexane<br>Toluene | LOW<br>MOD |
| Styrene ethylene butylene styrene | 37.07 | 61.7 | 79.3 | Petroleum hydrocarbons<br>Xylene | NA<br>MOD |
| Nitrile | 31.5 | 59.6 | 271.5 | Methyl ethyl ketone | MOD |

* From Jennings D, Eyre D, Small M: The safety categorization of sealants according to their volatile emissions. Ottawa, Ministry of Energy, Mines and Resources, Government of Canada, 1988.

* THR = Summary toxicity statement from Irving Sax, Dangerous Properties of Industrial Materials, Fifth Edition. New York: Van Nostrand Reinhold, 1979. MOD = moderate.

A styrene butadiene rubber compound was calculated to lose 35% of the original sample weight when fully dried at 253 hours. Of the original weight 16.4% was lost in the first 48 hours. The emissions were aliphatic hydrocarbons and xylene.

Meanwhile, a one-part chlorosulfonated polyethylene product lost only 4.4% of the original sample weight in the first 48 hours and a calculated 14.4% when fully dried. The emissions were primarily xylene and the complete drying time was estimated at 447 hours.

A one-part polyurethane lost nearly the same amount when fully dried but lost only 1.2% of the original sample weight after 48 hours. Its emissions were also primarily xylene. Its complete drying time was estimated at 8,269 hours, nearly a year.

Silicone caulk lost 2% of its original weight after 48 hours. The researchers calculated a total loss of 2.5% in the next 487 hours. The VOC emissions were xylene, considered moderately toxic by Sax.[27] A summary listing of the Saskatchewan research is contained in Table 6.

From Table 5 it is evident that product characteristics can vary considerably. A compound may have very high emissions but dry rather quickly. Another may have low total emissions and dry slowly. Every other combination is also found. These facts make it clear that it is important to obtain actual performance data on the products, that it does make a difference which products are chosen, and that there is no correlation between total emissions and complete drying time.

Slow-drying compounds or products are the worst from an indoor air quality perspective unless their emissions are either nontoxic and nonirritating or negligible. Fast-drying products like the styrene butadiene rubber compound emit significant fractions (1/3–3/5) of their total weight, but they do so in a matter of 3 to 10 days, mostly in the first 2 or 3 days. Thus, by applying these products while using adequate ventilation, the product is reasonably acceptable for indoor air.

The size of the bead is also variable. The tests were done with beads 6 m by 6 mm by 304.8 mm (19.68 ft × .24 in × 1 ft). Bead size affects the emission rate. Emission processes are a function of evaporation from the surface and diffusion through the material to the surface. Of course, a flat section will have more surface area and less interior volume than a round section. Drying or evaporation will be quickest from the surface and slowest from the center. The further vapors must travel to reach the surface, the slower the drying time.

The physical structure of the material will also affect the outgas rate, although this cannot be predicted precisely without considerable research. Some materials quickly form a skin on the surface. This skin inhibits outgassing after it is formed. However, experimental testing of various products by the Saskatchewan researchers showed that after a few hours, the emissions tend to become more consistent among products regardless of some irregularities during the first few hours.[11]

## PHASE 4. ANALYSIS AND RECOMMENDATIONS

The most effective way to obtain "clean" products is to place as much responsibility as possible on the product manufacturer to control emissions and to provide data. A number of standard "guide" specifications have been developed that can be used to direct the potential vendors to provide products and information about them.[15a]

### General Considerations

Certain materials are more important sources of VOCs than others. These include carpets, adhesives, caulks, sealants, paints, insulations, and office work station furnishings. Each of these products is addressed below. Suggested approaches for any of these materials may be applicable for other materials, although they are not repeated in detail for each product.

### Carpet

Carpet installations are frequently implicated in indoor air pollution incidents. There is not enough information currently available on carpet emissions to permit selection or detailed screening of products on the basis of carpet composition or emissions.





Manufacturers of commercial carpet products are keenly aware of indoor air quality issues, and several have initiated testing programs. Data from these tests can be helpful in evaluating candidate products. Manufacturers may use the data to modify their products or to use in the event of a lawsuit involving their products. Their activities also may result in marketing themes based on claims of low emissions.

Of course, different test procedures will produce different results. If you receive emissions data from a manufacturer, be sure to request a copy of the test method. The history of the sample prior to testing can also significantly affect test results. Important factors include exposure to air movement, temperature, and conditioning prior to testing.

Levels of emissions decline rather rapidly. In some tests, the reported decreases are on the order of 10 to 50 times within the first 3 to 6 weeks of exposure to the environment after installation.[11,14,32,34]

#### PLANS AND SPECIFICATIONS

Products such as carpets are normally specified in the "construction documents," which consist of "working drawings" and "construction specifications." Specific designations of materials, equipment, and layouts are developed in the preparation of the contract documents. Products are considered and selected. Here architects, engineers, interior designers, and their clients can exert enormous influence on the providers of the products.

***Model "Guide" Specifications:***

Following are some examples of carpet specifications that can be generally adapted for many building products. Specific language should be developed for each product of concern.

1. Carpets (or whatever product) shall be designed, manufactured, handled, installed, and maintained in a manner that will produce the least harmful effects on occupants of the building.
2. The manufacturer of the carpet shall avoid unnecessary use of chemicals that are toxic or irritating to humans in the manufacture, treatment, or handling of the carpet products.
3. The manufacturer shall implement measures to reduce as much as possible installed carpet chemical emissions that are toxic or irritating to humans.
4. The carpet manufacturer shall provide a specification for the installation of the carpet that uses the least quantity of adhesive necessary to satisfactorily maintain the required performance of the carpet product. Furthermore, adhesive selection shall be based on the lowest level of volatile organic chemical emissions released into the building air. Where more than one adhesive is suitable and the emission rates are similar, the adhesive with the least toxic or irritating contents shall be specified.
5. Manufacturers of carpet shall submit the following for review by the owners and their agents:

- A list of all chemicals used in the manufacture of the carpet. This list shall include a breakdown of the contents by weight, volume, or both.
- A description of any procedures used by the manufacturer to minimize the emissions of VOCs from their product(s).
- A description of all testing performed by the manufacturer, its agents, contractors, or any other party that provides information on the chemical composition of the finished product; the emission rates of VOCs from the

finished product; and a list of all chemicals found in emissions testing, headspace testing, or other tests providing evidence of the emission products, quantities, and rates. For all such tests, a description of the test methods used, the history and conditioning of the samples tested prior to the test process, the raw data obtained from such tests, the agency performing the tests, and the reported results of the testing process should be included.

*Submittals Review.* The submittals in response to the specifications should be reviewed and compared with any available emission test results for each candidate product. On the basis of the submitted data, including but not limited to the test results, the designer or investigator can determine the need for additional testing or other evaluations.

### Conditioning Carpets

The designer or health professional can determine the need for carpet product conditioning prior to installation in the building based on the data obtained from manufacturers and testing. Conditioning can occur at the factory prior to shipment, at the site prior to installation, or *in situ.*

VOC emissions are a function of material temperature, air movement above the carpet, concentration of VOCs in the air above the carpet, and the distribution of VOCs in the carpet. Elevating temperature, maintaining good air movement above the carpet, and providing good ventilation accelerates emissions. Since most floors are relatively massive, it takes far longer to raise their temperatures measurably than it takes to increase air temperature. Trying to condition carpets in place may take several days and perhaps as long as a week to achieve any real effect.

It is far better to condition carpets at the end of the manufacturing process. A conditioning step after manufacturing might involve running the carpet through a well-ventilated, heated chamber. The carpet manufacturing process involves several steps in which the product is heated to very high temperatures, but this takes place in closed chambers. Thus, emissions do not escape, although they may move from the interior to the surface of the product. Chemical changes also occur during the heat cycles.

VOCs may be loaded on the surface of carpet fibers as a result of the process described above. When carpets are first exposed to the air in a building, there is a burst of VOC release; this explains the noticeable odor. If this burst occurs outside the building, this will considerably reduce the amount of off-gassing that will occur indoors.

Whether it is done at the factory, in a warehouse, or outdoors, it is worth considerable extra effort to provide for off-gassing after bringing the carpet product into the building.

## Adhesives

Carpet and other flooring adhesives are also sources of indoor air pollutants. Adhesive specifications are typically prepared by the carpet manufacturer. Many indoor air quality concerns may be addressed by minimizing the quantity of adhesive used and the toxic or irritating chemical constituents of the adhesive. Maximizing ventilation during the carpet installation can reduce VOC residues from carpet adhesives.





EPA's Public Access Buildings Study found VOC emissions nine times greater from carpet adhesive than from the carpet for which it was used. Adhesive emissions may occur faster, however, and long-term comparisons were not conducted in that study.[28]

The following can be included in the carpet adhesive specifications:

- Clearly stated concern about indoor air quality and potential chemical emissions from the adhesive product. Specific concerns include odor, irritation, and toxicity of adhesive emissions.
- The adhesive specification by the carpet manufacturer should call for the smallest quantity of adhesive consistent with the requirements of product application.
- The adhesive should have the lowest content by volume of toxic or irritating chemicals while meeting with the requirements for product application.
- The manufacturer(s) of the candidate adhesive product(s) should be required to submit the same type of information suggested above for carpet manufacturers.

The submittals should be reviewed to determine the need for further evaluation, testing, or modifications of the products. If data are obtained for several products, the results can be compared. Investigators should not hesitate to ask manufacturers and suppliers questions. Answers to important questions should be obtained in writing. If the data are difficult to interpret, an industrial or analytical chemist, industrial hygienist, or other qualified professional should be retained to assist in the interpretation.

### Temporary Ventilation

Temporary, special ventilation may be required during and immediately following carpet installation to reduce the airborne concentrations of carpet and carpet-adhesive vapors. In general, such ventilation is almost always a good idea. The longer the ventilation period after installation, the lower the residues when the space is occupied.

The contract specifications should require that the HVAC system be operational prior to the installation of the carpet. The preferred HVAC system operation would use supply air fans and ducts only; exhaust ducts would be sealed and exhaust fans disabled. Exhaust would be provided through windows (if operable). This will reduce contamination of return air ducts, plenums, and insulation materials. If operable windows are not present, temporary openings can be created by temporarily removing window glass. In some special cases, temporary exhaust fans will be needed to pull exhaust air from deep interior locations. Stair towers and other paths to the exterior are useful for exhausting air from the building during the temporary ventilation. This temporary ventilation approach is also useful during painting, installation of furnishings, and other such operations both during construction and after occupancy.

## Vinyl Composition Tile and Other Flooring Products

Air quality considerations for many other flooring products are similar to those for carpet and carpet adhesive. Minimizing the quantity of adhesive used, the toxic or irritating chemical components of the adhesives, and the emissions from the product are the goals. Specifications should advise contractors and manufacturers about indoor air quality and require submission of

the relevant data. Temporary ventilation will be useful in reducing air levels and residues of emissions.

### Caulks, Sealants, Glazing Compounds, Joint Fillers

These "wet" building products may contain and emit VOCs after installation in the building. Considerations similar to those for adhesives apply. The range of measured test emissions is very great. Therefore, selecting products with low emissions and low content of toxic or irritating components can significantly reduce occupant exposure to indoor air pollutants.

Specifications for "wet" building products should follow the same general procedures described above for adhesives. Specifications should require use of the minimum quantities of these materials necessary to perform the required function, adequate ventilation during and after installation, and data from the manufacturers on contents and emissions.

### Paints

Paint products contain a variety of VOCs incorporated as drying agents, flattening agents, mildewcides, fungicides, preservatives, and others. These VOCs have been measured in indoor air many months after application of the paints. There is a wide range of formulations with an equally wide range of emission rates and chemical contents. Data from the EPA Public Access Buildings Study showed a hundredfold difference in the VOC emissions from one latex paint and another[28] (see Table 7).

L.24

Specifications should be similar to those discussed for the products identified above. Candidate paint products should be evaluated according to procedures described above for adhesives and other "wet" products. Maximum feasible all-outside-air ventilation should be used during the application of paints to accelerate emissions and remove residues from the building.

### Insulations

Insulation materials emit indoor air contaminants from their original composition. They also re-emit chemicals that are absorbed on their very large surface areas. Insulations used for acoustic control are often "fleecy" in order to enhance their sound absorption capabilities. However, the fleeciness enhances adsorption of VOCs and retention of VOCs within the building.

Acoustic insulations, especially those used in HVAC duct work, are particularly challenging from an indoor air quality perspective. Fleecy duct linings inevitably become contaminated by particles and by biological aerosols, which leads to microbial amplification. Covering them with impermeable membranes reduces their effectiveness for noise-control purposes.

It is most important to limit acoustical insulation application to essential uses. Where acceptable, apply it to the exterior of ductwork. Use sound baffles rather than insulations where they will do the job.

Thermal- and fireproof-insulation materials do not necessarily need fleecy surfaces in order to work. However, the economical manufacture or application of the materials often results in a fleecy surface. Where possible, they should be coated with a smooth and impermeable membrane to reduce the adsorption of VOCs on their considerable surfaces.

To reduce the potential for microbial growth on acoustic and thermal insulations, keep fibrous duct insulations clean and limit humidity within the





*TABLE 7.* Summary of Emission Results

| | Emission Rate (μg/m²h) | | | |
|---|---|---|---|---|
| Sample[a] | Aliphatic and Oxygenated Aliphatic Hydrocarbons | Aromatic Hydrocarbons | Halogenated Hydrocarbons | All Target Compounds |
| Cove adhesive | a | a | a | 5,000 |
| Latex caulk | 252 | 380 | 5.2 | 637 |
| Latex paint (Glidden) | 111 | 52 | 86 | 249 |
| Carpet adhesive | 136 | 98 | —[b] | 234 |
| Black rubber molding | 24 | 78 | 0.88 | 103 |
| Small diameter telephone cable | 33 | 26 | 1.4 | 60 |
| Vinyl cove molding | 31 | 14 | 0.62 | 46 |
| Linoleum tile | 6.0 | 35 | 4.0 | 45 |
| Large diameter telephone cable | 14 | 20 | 4.3 | 38 |
| Carpet | 27 | 9.4 | — | 36 |
| Vinyl edge molding | 18 | 12 | 0.41 | 30 |
| Particleboard | 27 | 1.1 | 0.14 | 28 |
| Polystyrene foam insulation | 0.19 | 20 | 1.4 | 22 |
| Tar paper | 3.2 | 3.1 | — | 6.3 |
| Primer/adhesive | 3.6 | 2.5 | — | 6.1 |
| Latex paint (Bruning) | — | 3.2 | — | 3.2 |
| Water repellent mineral board | 1.1 | 0.43 | — | 1.5 |
| Cement block | — | 0.39 | 0.15 | 0.54 |
| PVC pipe | — | 0.53 | — | 0.53 |
| Duct insulation | 0.13 | 0.15 | — | 0.28 |
| Treated metal roofing | — | 0.19 | 0.06 | 0.25 |
| Urethane sealing | — | 0.13 | — | 0.13 |
| Fiberglass insulation | — | 0.08 | — | 0.80 |
| Exterior mineral board | — | 0.03 | — | 0.03 |
| Interior mineral board | — | — | — | — |
| Ceiling tile | — | — | — | — |
| Red clay brick | — | — | — | — |
| Plastic laminate | — | — | — | — |
| Plastic outlet cover | — | — | — | — |
| Joint compound | — | — | — | — |
| Linoleum tile cement | — | — | — | — |

[a] Emission rate for cove adhesive is a minimum value; sample was overloaded. It is estimated that cove adhesive is one of the highest emitters of volatile organics.
[b] No detectable emissions.

ducts. Prevent condensation by properly locating humidification or dehumidification equipment and by minimizing condensate "blow-off."

Be sure that lined ductwork and plenums can be easily inspected and cleaned.

### Work Station Panels

Because of the very large surface area of work station panels, they are an extremely important factor in indoor air quality. Their VOC contents can be

emitted to indoor air. Their fabric covering can serve as an adsorption surface for VOCs emitted from other products or occupant activities and then act as a "secondary source" of emissions.

One type of interior partition (work station panel) contains chipboard material used for septums. While only 1/16 inch thick, it is made from recycled paper materials similar to the composition of food boxes or the chipboard found in tablets of writing paper.

If inspectors find the panel fabric is soiled, it is cleaned in the plant before being bagged in polyethylene film for shipment. About 25% of panels must have some cleaning. Cleaning is with 1,1,1,-trichloroethane (TCA; methyl chloroform), a common cleaning solvent. It is a relatively volatile compound, which means that most of it will evaporate rather quickly when exposed to air in a well-ventilated space. It also means that a substantial portion of the residue on the fabric at time of packaging will be released in the building when the packaging is removed.

TCA is one of many known eye and mucous membrane irritants commonly found in indoor air. It is also used as a pesticide and in textile processing. Because of its irritant potential, its concentration in indoor air should be minimized through all reasonable measures.

If possible, allow TCA-cleaned panels to be aired out before being packaged for shipping. The furnishings industry is becoming much more aware of indoor air quality concerns, and some manufacturers are quite willing to discuss measures to minimize problems.

One large manufacturer of office furnishings is currently negotiating a contract with a testing laboratory where emissions from their products will be identified and quantified. This will motivate other large manufacturers to undertake similar programs.

A panel from another large manufacturer was recently tested and determined to have very high emissions of a solvent believed to be fairly toxic or irritating to humans. It is a chemical cousin of glycol ether solvents. A 1983 NIOSH current intelligence bulletin warned of its hazards.[24] We have not found definitive toxicity information on this particular product, but its odor alone was sufficient to cause concern.

The molded fiberglass or other acoustic absorbant or barrier material behind the fabric can be a considerable source of VOCs as well as a matrix and food source for microorganisms. Investigation of the contents, emissions, and alternatives should be completed before contracting for office furnishings.

### General Recommendations

1. Communicate with manufacturers' technical representatives to obtain the most comprehensive test reports available. If no testing has been done, consider using other products.
2. Evaluate results of testing and adopt mitigation measures based on those results. Consider possible changes in materials, airing-out at the factory prior to packaging, airing-out outside the building prior to installation, or conditioning *in situ*.
3. Consider the need for independent testing. More laboratories are becoming available to do this type of work.
4. Consider random testing of panels arriving on site to monitor emissions.
5. Include specification statements regarding concerns, identification of components, requirements for controlling emissions to minimum levels, and the need to address concerns prior to initiating manufacturing of the panels.





## Sponge Effect

When furnishings are installed or finishes are applied in spaces containing high surface area materials, such as carpeting or ceiling tiles or free-standing partitions, much of the initially released VOC will be absorbed onto other material surfaces. The quantities adsorbed will depend on the total surface area exposed as well as the air exchange rate in the space. The rougher surfaces of insulation materials, textiles, and carpets would be expected to adsorb large quantities of VOCs. In fact, the available surface area for adsorption on such "fleecy" materials is many times the plane surface measurement.

When ventilation is reduced or turned off (at night and on weekends, or during warm and cold outdoor temperature periods), indoor air VOC concentrations will tend toward equilibrium; that is, they will rise until there is a balance between emissions from sources and removal from air by ventilation, chemical reaction, or surface adsorption. As VOCs are emitted from materials, they will be adsorbed on surfaces. The higher the temperature, the higher the emissions and air concentrations. The lower the ventilation rate, the more they will be adsorbed on interior surfaces.

An experiment by Berglund et al. demonstrated the "sponge" effect of the distribution of VOCs in enclosed spaces.[3] In the experiment conducted at a Swedish preschool, a stainless steel chamber was lined with floor, wall, and ceiling materials removed from the building. Initial VOC levels in the chamber were similar to those measured inside the preschool, about 100 $\mu g/m^3$. It took 30 days to eliminate the observed sponge effect by supplying 0.5 air changes per hour of outdoor air to the chamber.

### Control Measures

The following measures will considerably shorten the time during which the sponge effect will contribute to elevated VOC indoor air levels:

1. Maximum outside air ventilation should be used during and following installation of finishes and furnishings to reduce air levels of VOCs emitted from new products and materials. Use temporary exhaust (through doors, operable windows, stair towers, and emergency exits) for exhausting air rather than the HVAC return system wherever feasible. It is important to operate ventilation systems 24 hours/day, 7/days per week during periods of elevated VOCs.
2. Protect installed materials (with vapor barriers, i.e., sealed plastic coverings) to the extent feasible, during use of VOC-containing finishing products such as adhesives and paints, and during installation of VOC-emitting furnishings and partitions.
3. Protect fiber-lined HVAC ducts and return-air plenums from air flows to avoid contamination of system components. Exposed upper surfaces of ceiling panels and spray-on insulation enclosing concealed spaces used as return air plenums may adsorb large quantities of VOCs if contaminated air is circulated through them.
4. Operate newly occupied building areas at the lowest temperatures acceptable to occupants. Temperature excursions can cause bursts of VOCs with low boiling points and cause episodic elevation of VOC levels.

## CONCLUSION

Frequently employed strategies to reduce airborne concentrations of VOCs include several methods: selecting materials with low emissions, treating

materials before use in a building, encapsulating or sealing materials in a building, or by dilution through increased ventilation. A major problem is that little is known about the specific health effects of most VOCs at the low concentrations usually found in indoor environments. Therefore, efforts are not focused on the end point—irritation or toxicity—but rather on the exposure. This is an acceptable approach in light of the absence of sufficient information to target efforts on the active or effective toxic or irritating materials.

## APPENDIX

### SOURCES OF INDOOR ORGANIC COMPOUNDS

Based on Tucker (ref. 33; see explanatory note at end of this table) 34 and other sources

| Compound[a] | Formula | Substantiated Sources[b] | Potential Sources[c] |
|---|---|---|---|
| Formaldehyde | $CH_2O$ | Unvented radiant gas space heaters, upholstery fabric, latex-backed fabric, plywood, particleboard, carpets, paneling, new clothing, fiberglass, paper plates & cups, ceiling panels, airducts, unvented range-top burner, unvented gas oven, urea foam insulation, floor covering, wallpaper, caulking compounds, jointing compound, floor varnish, adhesive, fiberboard, chipboard, linoleum, floor lacquer, calcium silicate sheet, gypsum board, tobacco smoke | |
| Methylene chloride | $CH_2Cl_2$ | Paint removers, aerosol finishers | |
| Carbon tetrachloride | $CCl_4$ | Grease cleaners | |
| Chloroform | $CHCl_3$ | Water, clothes washer | |
| Bromoform | $CHBr_3$ | | Medicinals |
| Trichlorofluoro-methane (F-11) | $CCl_3F$ | Refrigerant | |
| Tetrachloroethylene | $C_2Cl_4$ | Dry cleaning | |
| 1,1,1-Trichloroethane | $C_2H_3Cl_3$ | Dry cleaning, cleaning fluid | |
| Trichloroethylene | $C_2HCl_3$ | | Solvent for paints and varnishes, degreasing in dry cleaning |
| Acetic acid | $C_2H_4O_2$ | Tobacco smoke | Food preservative, cooking, solvent for gums, resins, caulks, sealants, glazing compounds, volatile oils |
| Acetaldehyde | $C_2H_4O$ | | Perfumes, flavors, dyes, tobacco smoke |
| Ethanol | $C_2H_6O$ | Fiberboard | Solvent, antifreeze, tobacco smoke |
| Isopropanol | $C_3H_8O$ | Particleboard | Antifreeze, solvent for gums, shellac, essential oils, cosmetics |

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| Compound | Formula | Substantiated Sources | Potential Sources |
|---|---|---|---|
| Acetone (propanone) | $C_3H_6O$ | Lacquer solvent | Tobacco smoke |
| Pyruvic acid | $C_3H_4O_3$ | | Medicinal ointments |
| Ethylacetate | $C_4H_8O_2$ | Linoleum floor covering | Artificial fruit essences; solvent for varnishes & lacquers; used in manuf. perfumes & artificial leather |
| Diethylamine | $C_4H_{11}N$ | | Used in resins, dyes, pharmaceuticals; used in manuf. rubber |
| Dimethylacetamide | $C_4H_{10}ON$ | | Solvent for organic reactions |
| n-Butylacetate | $C_4H_{10}O_2$ | Floor lacquer | |
| i-Butylacetate | $C_4H_{10}O_2$ | Floor lacquer | |
| 1,4-Dioxane | $C_4H_8O_2$ | | Solvent for many oils, waxes, dyes, cellulose acetate |
| n-Butanol | $C_4H_{10}O$ | Edge sealing, moulding tape, jointing compound, cement flagstone, linoleum floor covering, floor lacquer | Flavors, perfumes, industrial cleaners, paint removers |
| i-Butanol | $C_4H_{10}O$ | Edge sealing, moulding tape, jointing compound, cement flagstone, linoleum floor covering, floor lacquer | Tobacco smoke |
| 2-Butanone (MEK) | $C_4H_8O$ | Floor/wall covering, calcium silicate sheet, fiberboard, caulking compounds, particleboard, tobacco smoke | Synthetic resins, tobacco smoke |
| 2-Ethoxy-ethanol (Cellosolve) | $C_4H_{10}O_2$ | Epoxy paint, latex paint, polyurethane varnish | |
| Pentane | $C_5H_{12}$ | Tobacco smoke | |
| 1-Amyl alcohol | $C_5H_{12}O$ | | Solvent in organic synthesis |
| Propyl acetate | $C_5H_{10}O_2$ | | Flavors, perfumes, plastics |
| n-Hexane | $C_6H_{14}$ | Chipboard, gypsum board, insulation board, floor covering, wallpaper, tobacco smoke | |
| Cyclohexane | $C_6H_{12}$ | Tobacco smoke | Solvent for lacquers and resins, paint & varnish remover |
| Cyclohexanone | $C_6H_{10}O$ | | Solvent for many resins and for DDT, also for fats & waxes |
| Hexanal | $C_6H_{12}O$ | Polyurethane wood finish | |
| 4-Methyl-2-Pentanone | $C_6H_{12}O$ | Floor/wall covering, tobacco smoke | |
| Methylcyclopentane | $C_6H_{12}$ | Tobacco smoke | |

| Compound | Formula | Substantiated Sources | Potential Sources |
|---|---|---|---|
| 2-Methylpentane (isohexane) | $C_6H_{14}$ | Chipboard, gypsum board, insulation foam, floor covering, wall paper, tobacco smoke | |
| 3-Methylpentane | $C_6H_{14}$ | Tobacco smoke | |
| Benzene | $C_6H_6$ | Smoking, adhesives, spot cleaners, paint remover, particleboard, tobacco smoke | |
| Chlorobenzene | $C_6H_5Cl$ | | Solvent for paint; used in manuf. DDT & phenol |
| o-Dichlorobenzene | $C_6H_4C_{12}$ | Deodorizers, moth crystals | |
| m-Dichlorobenzene | $C_6H_4C_{12}$ | Deodorizers, moth crystals | |
| p-Dichlorobenzene | $C_6H_4C_{12}$ | Deodorizers, moth crystals | |
| Hexachlorobenzene | $C_6Cl_6$ | Fungicide | |
| Tetrachlorophenol | $C_6H_2Cl_4O$ | Wood preservative | |
| 2-Ethoxyethylacetate | $C_6H_{12}O_3$ | Floor lacquer, epoxy paints | |
| Pentachlorophenol | $C_6HCl_5O$ | Wood preservative, disinfectant, fungicide | Paints, wallpaper adhesive, textiles, wood finishes, leather tanning, canvas, rope, paper, carpet shampoo |
| Iso-butylacetate | $C_6H_{12}O_2$ | | Flavorings, solvent |
| Butylacetate | $C_6H_{12}O_2$ | Floor lacquer | |
| Toluene | $C_7H_8$ | Solvent-based adhesive, water-based adhesive, edge sealing, moulding tape, wallpaper, jointing compound, calcium silicate sheet, floor covering, vinyl coated wallpaper, caulking compounds, paint, chipboard, linoleum floor covering, kerosene heaters, tobacco smoke | |
| Butyl acrylate | $C_7H_{12}O_2$ | | Used as monomer in manuf. of polymers & resins for textile & leather finishes |
| Heptane | $C_7H_{16}$ | Floor covering, floor varnish, kerosene heaters | |
| Benzaldehyde | $C_7H_6O$ | Fiberboard, particleboard | |
| Ethylbenzene | $C_8H_{10}$ | Floor/wall covering, insulation foam, chipboard, caulking compounds, jointing compound, fiberboard, calcium silicate sheet, adhesives, floor lacquer, grease cleaners | |
| Styrene | $C_8H_8$ | Insulation foam, jointing compound, fiberboard, tobacco smoke | |

1.27



| Compound | Formula | Substantiated Sources | Potential Sources |
|---|---|---|---|
| Xylenes | $C_8H_{10}$ | Adhesives, jointing compound, wallpaper, caulking compounds, floor covering, floor lacquer, grease cleaners, shoe dye, tobacco smoke, kerosene heaters, varnish, kerosene heaters | |
| Nonane | $C_9H_2O$ | Wallpaper, caulking compounds, floor covering, chipboard, adhesives, cement flagstone, jointing compound, floor varnish, kerosene heaters, floor wax | |
| Ethyl toluene | $C_9H_{12}$ | Floor wax | |
| o-Ethyltoluene | $C_9H_{12}$ | Floor wax | |
| m,p-Ethyltoluene | $C_9H_{12}$ | Floor wax | |
| m-Ethyltoluene | $C_9H_{12}$ | Floor wax | |
| Quinolone | $C_9H_7N$ | | Used in manuf. of dyes; solvent for resins |
| Isoquinolone | $C_9H_7N$ | | Used in synthesis of dyes and insecticides, rubber accelerator |
| Indane (hydrindene) | $C_9H_{10}$ | | Constituent of coal tar |
| 1,2,3 Trimethylbenzene | $C_9H_{12}$ | Floor/wall covering, floor wax | |
| 1,2,4 Trimethylbenzene | $C_9H_{12}$ | Floor/wall covering, linoleum floor covering, caulking compounds, vinyl coated wallpaper, jointing compound, cement flagstone, floor varnish, chipboard, floor wax | |
| 1,3,5 Trimethylbenzene | $C_9H_{12}$ | Caulking compounds, floor/wall covering, floor wax | |
| n-Propylbenzene | $C_9H_{12}$ | Adhesives, floor/wall covering, chipboard, paint, caulking compounds, insulation foam, kerosene heaters | |
| n-Butylbenzene | $C_{10}H_{14}$ | | Solvent |
| Limonene | $C_{10}H_{16}$ | Paint, adhesives, chipboard, detergents | |
| Pinene | $C_{10}H_{16}$ | | Used in manuf. of camphor, insecticides, solvents, plasticizers, & perfumes |
| a-Pinene | $C_{10}H_{16}$ | Cement flagstone, fiberboard, gypsum board, adhesive, insulation sheets, chipboard, calcium silicate sheet | |
| a-Terpinene | $C_{10}H_{16}$ | | Oil of lemon |
| Camphene | $C_{10}H_{16}$ | | Occurs in many essential oils |
| Camphor | $C_{10}H_{16}O$ | Moth crystals | |
| Naphthalene (Tetralin) | $C_{10}H_{12}$ | Moth crystals | |

| Compound | Formula | Substantiated Sources | Potential Sources |
|---|---|---|---|
| Undecane | $C_{11}H_{24}$ | Wallpaper, gypsum board, floor/wall covering, joint compound, chipboard, floor varnish, paints, paint removers | |
| Dodecane | $C_{12}H_{26}$ | Floor varnish, floor/wall covering, kerosene heaters | |
| 4-Phenylcyclohexene | $C_{12}H_{14}$ | Latex-backed carpet | |
| Nonylphenol isomers | $C_{15}H_{24}O$ | | Used in manuf. of lubricating oil additives, resins, plasticizers, & surface active agents |
| Dibutylphthalate | $C_{16}H_{22}O_4$ | Plastics | |

NOTES:

[a] Selected compounds that have been measured in indoor air and that may have come from material sources.

[b] Source types for which quantitative data on emissions have been obtained by chamber tests, or for which qualitative data are available (e.g., from headspace testing).

[c] Source types known to contain the compound. Not all products of the source type will necessarily have the compound, however.

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